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S. W. STRATTON, Director

ON THE TEMPERATURE OF THE  
ARC

BY

C. W. Waidner, Associate Physicist

and

G. K. Burgess, Assistant Physicist

*Bureau of Standards*

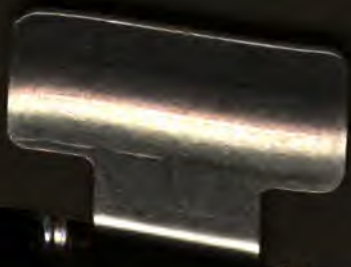
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# ON THE TEMPERATURE OF THE ARC

BY

C. W. WAIDNER, Associate Physicist  
and  
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*Bureau of Standards*

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## ON THE TEMPERATURE OF THE ARC.

By C. W. Waidner and G. K. Burgess.

The comparison of the methods of extrapolation that must be resorted to in the estimation of extremely high temperatures is of growing importance in establishing a satisfactory tentative scale of temperature which is already required in many scientific and industrial operations.

In a study of the possibilities of the application of optical and radiation methods of pyrometry to the estimation of extremely high temperatures we have been led to compare a number of carefully calibrated optical pyrometers at the "temperature of the arc."

The early attempts to estimate the so-called temperature of the arc, or more precisely, the temperature of the hottest portion of the positive crater, were based on the extrapolation of empirical relations connecting radiation and temperature (Newton, Dulong and Petit, Rosetti, etc.), that were only applicable through very narrow ranges of temperature, and the results to which they have led are now only of historical interest.

The first important measurement was that of Le Chatelier,<sup>a</sup> who determined for a number of bodies the relation between the photometric intensity of the red light emitted and the temperature. The photometric measurements were made with his optical pyrometer, and the temperature measurements with the now well-known Le Chatelier thermocouple (platinum, platinum-rhodium 10 per cent). This empirical relation is based on experiments extending over the range 700° C. to nearly 1800° C. Le Chatelier found by the extrapolation of this relation ( $I = 10^{6.7} T^{-\frac{2210}{T}}$ ) for the temperature of the arc 4400° abs. The red light was obtained by passing the radiation through red glass, which probably lets through the shorter wave lengths at high temperatures, so that the measured intensity would increase more rapidly than the formula would indicate. This would act in the direction of making the result come out too high.

<sup>a</sup> Le Chatelier: C. R., 114, p. 737; 1892; J. de Phys. (3), 1, p. 185; 1892.



Violle<sup>a</sup> made an estimate of the temperature of the arc by a calorimetric method. A small removable button of carbon on the end of the positive crater was dropped into the calorimeter. The specific heat of carbon was measured and found to obey a linear relation for a considerable range above 1000°, and the relation thus established was assumed to hold as far as the temperature of the arc. The final value found by Violle was given as 3875° abs. Among the great experimental difficulties of this method are those due to loss of heat by the button in falling to the calorimeter and to nonuniformity of heating. Violle investigated these by varying the height of fall and size of the button. In general criticism of this method it should be noted that the specific heat of most substances increases more rapidly as the temperature corresponding to change of state is approached than at low temperatures. Although the difficulties of this method are very great—as admitted by Violle—the result is nevertheless interesting as a determination by a method widely different from those usually employed, based on the extrapolation of relations connecting radiation and temperature.

Wilson and Gray<sup>b</sup> made an estimate of the temperature of the arc by a method in which the radiation from the positive crater falling on one junction of a differential radiomicrometer was balanced by the radiation on the other junction from a known area of incandescent polished platinum strip, whose temperature was measured by its expansion after the principle of the Joly melderometer. The relation between the radiation of polished platinum and of platinum covered with copper oxide was then determined and the assumption made that the radiation from the carbon obeyed the same law as from the copper oxide, which is very nearly the case. Knowing then the apparent areas of the two sources of radiation, and knowing the relation connecting radiation and temperature, they could at once find the temperature to which the platinum strip would have to be raised to balance the arc if the apparent areas were equal. The result to which these experimenters were led was 3600° abs. In discussing this experiment which was admirably carried out it must be remembered that it was done at a time when the laws of radiation were not so well understood as they were a few years later. The method of measuring the temperature made use of in these experiments is capable of considerable precision. Their temperature scale is probably about 20° low at 1000°, inasmuch as the melting point of gold was taken as

<sup>a</sup> Violle: C. R., 95, p. 1273; J. de Phys. (3), 2, p. 545; 1893; C. R., 120, p. 868; 1895.

<sup>b</sup> Wilson and Gray: Proc. Roy. Soc., 58, p. 24; 1895; Phil. Trans. A., 185, p. 361, 1894, for details of apparatus, same as used in estimation of temperature of the sun.

1041° in the calibration of the platinum strip. The radiation of the bare platinum was found to increase approximately as the 4th power of the absolute temperature and of the blackened platinum about as the 3.4th power. This is not in agreement with subsequent researches of Paschen and of Lummer, Pringsheim, and Kurlbaum. The bare platinum was inclosed in a gilt case, which made it approximate more or less to a black body. The strongest criticism of this method is undoubtedly that it is based on the extrapolation of an empirical relation which was studied only through a comparatively narrow range of temperature (650° to 1150°), and the results can not therefore be given so much weight as those obtained by the extrapolation of Planck's law, which has been found to satisfy the results of experiments throughout the range from -200° C. to +1500° C.

Wanner<sup>a</sup> studied experimentally the relation connecting the temperature and the photometric intensity of monochromatic light of different wave lengths emitted by several black bodies of different construction, up to about 1400° absolute, and found that the results were in agreement with Wien's relation for the spectral distribution

of energy for a black body,  $J = c_1 \lambda^{-5} e^{-\frac{c_2}{\lambda T}}$ , as was shown by the linear

relation between  $\log J$  and  $\frac{1}{T}$ . Wanner then applied this method to an estimation of the temperature of the arc, by comparing with a spectrophotometer the intensity of the red ( $\lambda = 0.6563\mu$ ) and green ( $\lambda = 0.5461\mu$ ) radiation with the intensity of the same radiation emitted by a black body (indirectly for convenience through the intermediary of an amylacetate flame whose radiation for these wave lengths had been compared with black body radiation). Using red light, Wanner finds for the temperature of the hottest portion of the positive crater 3720°, and using green light 3700° abs. when cored carbons (Dochtkohle) are used; using retort carbons he finds for measurements with the red and green light 3875° and 3895° abs., respectively. If it can be assumed that the Wien equation continues to hold for such extremely high temperatures, which will be referred to again, this determination of Wanner must be given considerable weight, as the method is capable of precision. It must be noted that inasmuch as this determination is based on the extrapolation of the Wien equation which applies to a black body, the temperature thus found is the "black body temperature," i. e., the temperature that a black body would have to emit light of the same intensity. Barring the presence

<sup>a</sup> Wanner: Ann. d. Phys., 2, p. 141; 1900.

of luminescence, this method therefore gives the lower limit of temperature, so that the true temperature of the positive crater must at least be higher, by an amount depending on how much its radiation differs from black body radiation.

Lummer and Pringsheim<sup>a</sup> made use of the relation  $\lambda_m T = \text{const.}$ , connecting the wave length  $\lambda_m$  having maximum energy and the absolute temperature  $T$  of the radiating body, to estimate the limiting temperatures of a number of incandescent bodies, such as the Nernst filament, the Wellsbach mantle, argand gas flame, and the electric arc. The value of the constant for a black body is 2940, according to their experiments, and 2921 by those of Paschen,<sup>b</sup> a most satisfactory agreement. For the radiation from polished platinum Lummer and Pringsheim have found for the constant 2630. Assuming, then, that the "displacement law" continues to hold, and that the radiation from the crater of the arc is of the same character as from the black body and platinum, and is intermediate between these, which they have shown is very probable, these investigators concluded that the temperature of the positive crater must be between

$$T_{\min} = \frac{2630}{0.7} = 3750^\circ \text{ and } T_{\max} = \frac{2940}{0.7} = 4200^\circ \text{ abs.}$$

From the flattened form of the energy curve and the effect of atmospheric absorption, it is difficult to locate the position of the maximum with precision. It must be said that the "displacement law" on which this method is based is one of the best established laws of radiation, both from the theoretical and experimental side.

By an examination of a spectral energy curve of the positive pole of an electric arc, in a paper by Abney and Festing,<sup>c</sup> F. W. Very<sup>d</sup> was led to fix the maximum at about  $0.73 \mu$ . This gives for the upper and lower limits between which the temperature of the positive carbon must lie

$$T_{\max} = \frac{2940}{0.73} = 4025^\circ \text{ abs.}$$

$$T_{\min} = \frac{2630}{0.73} = 3600^\circ \text{ abs.}$$

<sup>a</sup> Lummer and Pringsheim: *Verh. d. Deutsch. Phys. Ges.*, 1, p. 235; 1899; *Verh. d. Deutsch. Phys. Ges.*, 3, p. 36; 1901.

<sup>b</sup> Paschen: *Ann. d. Phys.*, 4, p. 277; 1901.

<sup>c</sup> Abney and Festing: *Proc. Roy. Soc.*, 85, p. 334, Diagram II; 1883.

<sup>d</sup> F. W. Very: *Astrophysical Journal*, 10, p. 208; 1899.

Petavel<sup>a</sup> has found that his observations on platinum radiation satisfy the formula

$$(t-400)=889.6\sqrt[6.9]{b}$$

where  $t$  is degrees centigrade and  $b$  the intrinsic brilliancy per square centimeter measured photometrically. For the crater of the arc he found  $b=11000$  candles per  $\text{cm}^2$ , which would give  $t=3830^\circ\text{C}$  (4100 abs.) assuming that carbon and platinum obey the same radiation law. This assumption gives too high a value for  $t$ . With the constants proper to carbon in the above formula, the method might give good results.

More recently Féry<sup>b</sup> has made estimates of this temperature by two different methods. In one the radiation from the positive carbon was focused by a fluorite lens on the blackened junction of a minute iron-constantan thermocouple which was joined in circuit with a galvanometer. A preliminary calibration of this thermo-electric telescope with the radiation from an electrically heated black body as far as  $1500^\circ\text{C}$  showed that the observed deflections of the galvanometer were in most satisfactory agreement with those calculated from the Stefan-Boltzmann law. By this method Féry was led to the value  $3763^\circ\text{abs.}$  as the "black body temperature" of the arc. In this connection it is of interest to note that Lummer and Kurlbaum<sup>c</sup> have found that while the energy of total radiation from iron oxide, which is, very approximately, the same as from carbon, is only 30 per cent of that from a black body at  $654^\circ\text{abs.}$ , at  $1481^\circ\text{abs.}$  it has already grown to 60 per cent. This would indicate that the "black body temperature of the arc," as found by the energy of total radiation from carbon, would not differ very much from its true temperature, probably by less than  $200^\circ$ .

Using the photometric method and a modified form of the Le Chatelier optical pyrometer and assuming that Wien's law continues to hold, Féry finds  $4140^\circ\text{abs.}$  with red light and  $4170^\circ\text{abs.}$  using green light. As an explanation of this high value, want of monochromatism of the glass used at once suggests itself. The explanation certainly applies for the usual red glasses that are sent out by Pellin with the Le Chatelier optical pyrometer. Moreover, the "center of light" transmission of this glass is nearer to  $0.631\mu$  than  $0.659\mu$ , the value usually assumed from Le Chatelier's early determinations, probably made with a different kind of glass.

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<sup>a</sup> Petavel: Phil. Trans. Roy. Soc., A 191, p. 515; 1898.

<sup>b</sup> Féry: C. R., 134, pp. 977, 1201; 1902.

<sup>c</sup> Lummer and Kurlbaum: Verh. Phys. Ges., Berlin, 17, p. 106; 1898.

## EXPERIMENTAL RESULTS.

The methods we have used are all dependent on the extrapolation of Wien's equation for the distribution of energy in the spectrum of a black body,

$$J = c_1 \lambda^{-5} e^{-\frac{c_2}{\lambda T}}$$

The researches of Lummer and Pringsheim,<sup>a</sup> Paschen,<sup>b</sup> Rubens and Kurlbaum,<sup>c</sup> and Beckmann<sup>d</sup> have shown that this law does not hold for long wave lengths and high temperatures. The results of experiment are better represented by the equation deduced by Planck.<sup>e</sup>

$$J = c_1 \frac{\lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}$$

The experiments of Rubens and Kurlbaum have shown that this equation is in most satisfactory agreement with the results of experiments throughout the widest range of measurable temperatures,  $-200^{\circ}$  C. to  $+1,500^{\circ}$  C., and for the longest waves of the infra red portion of the spectrum obtained by multiple reflection from fluorite ( $\lambda = 24.0\mu$  and  $31.6\mu$ ) and rock salt ( $\lambda = 51.2\mu$ ) surfaces.

However, for the wave lengths of the visible spectrum, and even for the region of the infra red in which the largest part of the total energy of the spectrum is found, Wien's law applies with sufficient precision. Lummer and Pringsheim have shown that for values of  $\lambda T$  less than 3000 Wien's equation represents the results of experiments to an order of accuracy of 1 per cent. For the photometric measurements in the visible spectrum where the wave length does not exceed  $0.65\mu$ , the use of Wien's equation is justified for extrapolation to temperatures exceeding  $4000^{\circ}$  C.

<sup>a</sup> Lummer and Pringsheim: *Verh. d. Deutsch. Phys. Ges.*, 1, pp. 23, 215; 1899; *ibid.* 2, p. 163; 1899; *ibid.* 3, p. 6; 1901. Lummer: *Sur le rayonnement des corps noirs: Int. Cong. Rep.*, Paris, 1900; p. 929.

<sup>b</sup> Paschen: *Ann. d. Phys.*, 4, p. 277; 1900.

<sup>c</sup> Rubens and Kurlbaum: *Ber. d. K. Akad. d. Wiss.*, Berlin, 41, p. 929; 1900; *Ann. d. Phys.*, 4, p. 649; 1900.

<sup>d</sup> H. Beckmann: *Inaug.-Dissert.*, Tübingen, 1898.

<sup>e</sup> Planck: *Verh. d. Deutsch. Phys. Ges.*, 2, pp. 202, 237; 1900; *Ann. d. Phys.*, 4, p. 553; 1901.

We have determined the temperature of the brightest portion of the positive crater of the electric arc by means of the three pyrometers devised, respectively, by Le Chatelier, Wanner, and Holborn and Kurlbaum. The three instruments are photometers. In the Wanner a narrow spectral band in the red is used as monochromatic source, while in the other two dependence has to be placed upon colored glasses for monochromatism. In the Holborn-Kurlbaum<sup>a</sup> pyrometer the tip of a very fine incandescent lamp filament is made to disappear against the bright background observed, by varying the current through the lamp. The current is then a function of the temperature which may be found by calibration against a thermocouple.

In the Wanner<sup>b</sup> instrument a polarizing device permits balancing photometrically the intensities of the same spectral hues coming from a standard light and the source observed. The angle of the analyzer may be converted into degrees of temperature by calibration. In the Le Chatelier<sup>c</sup> instrument the light from the source is cut down by a cat's-eye diaphragm until photometric equality is had with light from a comparison source, when from the opening of the cat's-eye the temperature may be calculated after the instrument has been calibrated.

Between such a bright source as the arc and any of these instruments it is necessary, in order to render photometric comparison possible, to interpose absorbing glasses whose absorption factors ( $K$ ) have to be determined for the different wave lengths used.

Wien's law gives:

$$(1) \quad \log_{10} K = \log \frac{J_1}{J_2} = \frac{c_2}{\lambda} \log_{10} e \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

where  $c_2 = 14500$  for a black body, where  $\lambda$  is expressed in  $\mu$ ,  $e$  is the base of Napierian logarithms,  $J_1$  and  $J_2$  are the light intensities expressed in any units corresponding to the temperatures  $T_1$  and  $T_2$ ,  $T_1$  being the absolute black-body temperature of the source and  $T_2$  its apparent temperature when the absorbing glasses are interposed. This formula may be used with any of the above pyrometers to determine the arc temperature when  $K$  is known and the reading of each instrument has been found for some source which can be viewed without the absorption glasses. As a convenient reference temperature, or source of constant intensity, that of the central area of a definite acetylene flame viewed normally was used. The apparent black body

<sup>a</sup> Holborn and Kurlbaum: Ann. d. Phys., 10, p. 225; 1902.

<sup>b</sup> Wanner: Phys. ZS., 3, p. 112; 1902.

<sup>c</sup> Le Chatelier: J. de Phys., (3), 1, p. 185; 1892.

temperature of this source was 1625 abs., the different instruments agreeing to within  $3^{\circ}$  in this determination. Each of the instruments was also calibrated over a considerable temperature range in terms of a thermocouple using a Lummer-Kurlbaum black body as source, thus obtaining a whole series of comparison points. The two methods gave concordant results.

The values of absorption factors ( $K$ ) vary with the wave lengths of the light used,  $K$  decreasing quite rapidly for shorter wave lengths. Thus a given absorbing glass gave  $K=1500$  for  $\lambda=0.651\mu$ , and only 360 for  $\lambda=0.550\mu$ . Also with these glasses the value of  $K$  for  $n$  glasses is not  $K^n$ , as is generally assumed, but something less than this quantity. Four glasses of the same quality and thickness gave, for  $\lambda=0.651\mu$ , the following results, as determined from a large number of observations, using all three pyrometers in this determination:

Number of glasses.....	1.	2.	3.	4.
Value of $K$ .....	11.9	137	1 500	15 500
Increment of $K$ .....	11.9	11.5	10.9	10.3

The results of our determination of the arc temperature for a current of 15 amperes are given in the three following tables. The carbons were exceptionally homogeneous, prepared especially for optical projections and arcing very readily. The positive carbon (13 mm diameter) was mounted horizontally and the negative (11 mm diameter) vertically. The potential across the arc was about 65 volts. In order to prevent the formation of a deep crater on the under side of the positive carbon, the latter was occasionally trimmed down so that the hottest part of the crater could be readily viewed in a horizontal line.

#### DETERMINATIONS.

##### WITH WANNER PYROMETER.

Date.	Wave length used.	$K$ = Absorption factor.	Absolute temperature of arc.
1904.	$\mu$		
June 20.....	0.656	1 500	3 660
20.....	.656	1 500	3 700
Mean .....	.....	.....	3 680

## DETERMINATIONS—Continued.

## WITH HOLBORN-KURLBAUM PYROMETER.

Date.	No. of lamp used in H.-K. py- rometer.	Wave length used.	K= absorption factor.	Absolute temperature of arc.
1904.		$\mu$		
June 14.....	132	0.651	1 500	3 670
14.....	156	.651	1 500	3 680
14.....	145	.651	1 500	3 680
15.....	132	.651	1 500	3 630
15.....	156	.651	1 500	3 690
15.....	145	.651	1 500	3 670
20.....	132	.630	1 350	3 750
15.....	156	.630	1 350	3 790
16.....	132	.550	360	3 640
Mean .....				3 690

## WITH LE CHATELIER OPTICAL PYROMETER.

Date.	Wave length used.	K = absorption factor.	Absolute temperature of arc.
1904.	$\mu$		
June 17.....	0.651	15 500	3 740
17.....	.651	15 500	3 750
17.....	.651	15 500	3 750
17.....	.651	15 500	3 690
18.....	.651	1 500	3 730
18.....	.630	14 850	3 680
18.....	.630	1 350	3 730
Mean .....			3 720



Although the three pyrometers give practically an identical value ( $3700^{\circ}$  abs.) for the arc temperature, yet we do not consider all the observations of equal weight. The red glass  $\lambda=0.630\mu$  is not sufficiently homogeneous for good photometric measurements; with the Holborn-Kurlbaum instrument, for instance, the filament of the lamp can not be made to disappear when using this glass. Glass  $\lambda\ 0.651\mu$ , on the other hand, leaves practically nothing to be desired as to its homogeneity, and the results obtained with it have the greatest certainty. The values of the equivalent wave lengths for the red glasses were verified by Dr. Nutting to an accuracy well within the limits of error from other sources.

The relative temperatures obtained with the various instruments are independent of the absorption factors, the latter being dependent upon the absorption glasses, which were the same for all the pyrometers, and upon the wave length used. The absolute values we have obtained for the arc temperatures would evidently be in error if the values of the absorption coefficients are incorrect. The values chosen are the best that could be deduced from several hundred observations made with all the pyrometers. The absorption factor for green light ( $\lambda=0.550\mu$ ) is, however, less well determined.

As to the pyrometers themselves and the reliance to be placed upon the results obtained with the different instruments, the greatest uncertainty seems to be with the Wanner, because it is more difficult with this instrument than with the others to be sure that one is sighting upon the desired spot, as the instrument is not a telescope; also, the extrapolation of the scale of this particular instrument is somewhat uncertain. As between the determinations with the Le Chatelier and Holborn-Kurlbaum instruments, the preference is in favor of the latter, as a smaller area is used in the photometry and there are more independent checks upon its calibration; thus, using three comparison lamps, identical results are obtained.

On the whole, a better agreement among different instruments employing such varied methods of measurement could hardly be expected at such a high temperature. Our experiments with pure graphite have shown that the value,  $3700^{\circ}$  abs., would not be increased by more than  $50^{\circ}$ . The effect of material of carbons and of current density will also be considered.

## VARIATIONS IN TEMPERATURE OF THE ARC.

(a) *With current.*—It is generally accepted, since Violle<sup>a</sup> so stated, that the temperature of the arc is independent of the current, and this temperature is assumed to be the boiling point of carbon. There are, however, at least two reasons for which we should expect this temperature to vary with the current. As the current is increased there will be a tendency to superheat the viscous carbon layer from which the vapor boils, even though this vapor does not have a higher temperature than the normal boiling point, and as it is this viscous layer which is observed, variations of current above a certain limit should be accompanied by changes in temperature. Again, with low current a smaller area is heated, so that it will be more cooled by conduction.

An examination of the observations from which it has been inferred that the arc temperature is independent of current seems to indicate that this conclusion is unwarranted, for no observer has published a series of results sufficiently concordant in themselves or of sufficient number to enable him to state with certainty whether or not the effect exists. This has been due largely to the tediousness or inadequacy of the methods employed.

The constancy of brightness was first announced as probable by Rossetti in 1878, and Violle was the first to state as a result of his own experiments that "the brightness of the positive carbon is rigorously independent of the electric power expended to produce the arc, changing from within the limits 10 amperes at 500 watts to 400 amperes at 34000 watts." Carbons of 3.5 cm diameter were used for the high currents, but no details of observations are published nor the precision of his spectrophotometric method, which is certainly sensitive, though it would be expected that any effect for very high currents would be neutralized, in part at least, by the larger carbons used. Furthermore, results with carbons of varying size and quality are not comparable. Although Violle showed undoubtedly that with carbons of different sizes adapted to carrying currents of from 10 to 400 amperes, there is no considerable change in temperature, yet it would seem that he did not show conclusively that for a given sized carbon there is no variation of temperature with current for the brightest portion of the positive crater.

Wilson and Gray found that changing from 14 to 25 amperes "the temperature then appeared to be a little higher than with the smaller current. \* \* \* Later experiments \* \* \* indicate an exact

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<sup>a</sup> Violle: J. de Phys. (3), 2, p. 545; 1893.

equality of temperature." They do not give any data, but their published observations on the arc temperature indicate that it would be difficult to detect variations by their method.

Wanner states that "changing the current one and a half times (15 to 22 amperes) remains without influence." Wanner's published results for a given kind of carbon are few in number (four) and vary over  $90^\circ$  under the same conditions, so that any differences due to current changes might be masked.

Our experiments on the variation of arc temperature with current were first made with a Holborn-Kurlbaum pyrometer, which is peculiarly well adapted for these measurements, as it is readily sighted, and thus the wandering of the brightest spot on the crater can be easily followed. A very small photometric area is employed, and observations may be taken rapidly within intervals of a few seconds.

In order to secure a good-sized image of the crater, so as to facilitate the photometric measurements, the instrument, provided with auxiliary lenses and suitable absorption glasses, was placed as near as possible (12 to 25 cm) to the arc, which was mounted as previously described. The current from a 120-volt storage battery was varied without the observer being aware of the actual changes, and to render the settings of the pyrometer as unbiased as possible an additional rheostat in its lamp circuit was also worked independently of the observer. No observations were taken on a hissing or humming arc, nor until the arc burned normally after changing current, and the conditions of constant length of arc and constant *P. D.* across the arc were very closely maintained, the latter being measured with a Weston voltmeter; the value of the *P. D.* was about 65 volts. Two observers obtained practically identical results, which are here summarized.

Date.	Number of observations.	Current in arc.	Temperature of arc (absolute).
		<i>Amperes.</i>	$^\circ$
June 23, 1904 .....	51	15	3690
	48	22	3727
	49	30	3782
June 28, 1904 .....	23	15	3690
	37	22	3741
	42	30	3762

A few observations were also taken with a current of 40 amperes, which indicated that the effect persists with increasing current density to the limit that the auxiliary apparatus would stand.

The precision with which this determination can be made on a single carbon with the Holborn-Kurlbaum instrument is shown by the observations of June 23, 1904, namely, that the probable error of the mean in any one of the three series on that date is less than  $3^{\circ}$ , and no photometric observation with a current of 15 amperes was as high as the mean value for 30 amperes. Whatever may be the best value for the arc temperature, this value is apparently a function of the current when the *P. D.* across the arc is a constant and the arc is burning normally.

If the current is kept constant and the *P. D.* varied, it is necessary to vary simultaneously the length of the arc; therefore, temperature results obtained by this method of varying the power are not directly comparable, as the length of the arc is a variable which is not easily eliminated quantitatively.

It does not seem that our finding a small temperature change with current can be explained on physiological grounds, due to contrast in light intensities entering the eye, since with the smallest current used the image of the hottest part of the crater was many times larger than the image of the filament of the comparison lamp. To further test this point we determined the difference in temperature with a Le Chatelier optical pyrometer provided with auxiliary lens and a very homogeneous red glass before the eyepiece. A number of consistent observations indicate that changing the current from 15 to 30 amperes causes a rise in temperature of about  $70^{\circ}$ . With this instrument the eye does not receive light except through a 1 mm<sup>2</sup> opening, so that the effects of the surrounding field can not influence the eye.

(b) *With the material of carbons.*—Wanner finds a difference of about  $170^{\circ}$  in changing from cored to retort carbon, the former giving a low value, and our experiments also show that the kind of carbon used will influence the apparent temperature of the arc. The homogeneous carbons described above gave us results  $40^{\circ}$  lower than with a very pure graphite furnished by the Acheson Company. This result was obtained both with the Holborn-Kurlbaum and Le Chatelier optical pyrometers.

In commercial carbons the presence of salts seems to facilitate the arcing, and with large currents a steadiness can be had which can not be approached with pure graphite carbons. It appears that the arc temperature, as determined with commercial carbons, is lower than the point obtained for pure carbon.

(c) *Effect on the arc as a standard of light.*—These questions are of interest in connection with the proposed use of the radiation from a definite area of the brightest part of the crater of the + carbon of the electric arc as a standard source of light. If the variations in temperature are as great as indicated in our experiments, a variation of current from 15 to 22 amperes (corresponding to a temperature variation of  $40^{\circ}$  C. in the temperature of the arc) would correspond to a variation in the photometric intensity of several per cent. Even with the same current and the same carbons our results appear to show relative time changes of photometric intensity that seem considerably greater than the experimental errors and which may be due to varying shape of the carbons and changes in current density, as well as variations in the composition of the material. While it would be possible to define the current, it would not be as easy to control the form of the crater and the current density in the region from which the light is to be taken.

Another difficulty in the above method of defining a light standard arises from the variations that may result from the use of different kinds of carbon, as shown above. The experiments of Wanner indicate an enormous change in the intensity of light due to this cause.

Blondel<sup>a</sup> recognized the objections to the use of a screened area of the positive crater as a primary standard of light and recommended its use as a secondary standard for arc photometry. He found the nature of the carbon to be important in determining the absolute brightness (of a square millimeter); thus for five different qualities of homogeneous carbon an average value of 158 candles was found, the extremes being 150 and 163. With cored carbons he obtained values lower than 130 candles for the maximum brightness.

#### CONCLUSION.

A *résumé* of the estimates of the arc temperature that have been discussed in the preceding pages is given in the table on the next page.

From this table it will be seen that the photometric methods based on the extrapolation of Wien's equation show that the "black body temperature of the arc" (pure graphite) is at least  $3750^{\circ}$  abs., so that its true temperature must be higher than this; it is not possible to state how much, in the absence of more definite knowledge concerning the departure of carbon from black body radiation. In the light of the best evidence that is at present available it would seem that the true

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<sup>a</sup> Blondel: Proc. Int. Elec. Congress, Chicago, 1893.

temperature of the hottest part of the positive carbon is between 3900° and 4000° absolute.

Observer.	Absolute temperature of the arc.	Method.
Le Chatelier .....	4370	Photometric: Intensity of red light.
Vigle .....	3870	Calorimetric: Specific heat of carbon.
Wilson and Gray.	3600	Total radiation of copper oxide, empirical relation for.
Wanner .....	<sup>a</sup> 3700-3900	(Varying with carbons used). Photometric in terms of Wien's law.
Very .....	Bet. 3600 and 4000	Wave-length of maximum energy, Wien's displacement law: $\lambda_m T = C$ .
Lummer and Pringsheim.	Bet. 3750 and 4200	Do.
Féry .....	<sup>a</sup> 3760	Total radiation: Stefan-Boltzmann law.
	<sup>a</sup> 4150	Photometric: Wien's law.
Waidner and Burgess.	<sup>a</sup> 3690	Holborn-Kurlbaum pyrometer.
	( <sup>b</sup> ) <sup>a</sup> 3680	Wanner pyrometer.
	<sup>a</sup> 3720	Le Chatelier pyrometer.

<sup>a</sup> Black body temperature.

<sup>b</sup> Pure graphite gives a temperature not over 50° higher.

If we are justified in assuming that the high values found by Le Chatelier and by Féry, using photometric methods, are satisfactorily explained by the reasons we have advanced, a comparison of the results contained in the above table will show, when we consider the experimental difficulties and uncertainties that may enter due to varying conditions of the arc (such as current strength, length of arc, quality of carbon, etc.), that the results obtained, dependent as they are on the extreme extrapolation of different laws, are in quite satisfactory agreement, and diminish somewhat the doubt which is always present when we must venture beyond the domain of experiment.

The value obtained by Féry for the "black body temperature" of the arc, by making use of the Stefan-Boltzmann law for the total radiation of a black body, is in most satisfactory agreement with the results obtained by Wanner, dependent on the extrapolation of the Wien-Planck relation, and is nearly identical with our own photometric determinations based on the same relation. It is interesting to note in

this connection that Lummer and Pringsheim<sup>a</sup> have found these laws in agreement at 2300° abs.

If we can assume that the Wien-Planck and the Stefan-Boltzmann relations continue to hold good for thermodynamic radiation at these high temperatures, it would seem, in view of the above fact, that the phenomena of luminescence plays no very important part in the radiation from the positive pole of the electric arc; for, if so, it might be expected to lead to higher values in the estimates based on the photometric methods than would be found by methods dependent on total radiation.

An examination of the available estimates of the temperature of the sun, made by methods based on the photometric intensity, seem to indicate that these methods lead to higher values than those based on the energy of total radiation. Thus, using the former method, Le Chatelier<sup>b</sup> finds 7900°<sup>c</sup> abs. The estimates,<sup>d</sup> based on total radiation and on the position of the wave length of maximum energy in the solar spectrum, lead to values in the neighborhood of 5500° to 6000° absolute. If this difference in the methods really exists, it would at least suggest the presence of luminescent radiation. It would also be of interest in this connection to use the photometric method with green and blue, in addition to red radiation, to see if the former led to higher values, as might be expected if luminescence played an important rôle.

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<sup>a</sup> Lummer and Pringsheim: *Verh. Deutschen Phys. Ges.* (5) I, p. 3; 1903.

<sup>b</sup> Le Chatelier: *C. R.*, 114, p. 737; 1892.

<sup>c</sup> As Le Chatelier's determination of the arc temperature is probably several hundred degrees high, his value of the effective temperature of the sun should be lowered.

<sup>d</sup> Day and Van Orstrand: *Astrophys. J.* 19, p. 39; 1904.









